DESCRIPTION

MASK AND MANUFACTURING METHOD USING MASK

5   The invention relates to a method of manufacture suitable for use in the manufacture of thin film device arrays, particularly but not exclusively for use in the production of active matrix liquid crystal displays (AMLCDs) as well as micro-electrical-mechanical systems (MEMS). The invention also relates to a mask used in such a method, the use of the mask and a method of
10   manufacture of the mask.

The reduction of the number of process steps and the simplification of process steps is an important means of reducing the manufacturing cost for devices such as AMLCDs and x-ray image sensors. One approach for
15   reducing the number of steps is to use a single photolithography step to define two levels of photoresist. The photo-mask used in such a process may have three regions. One region is completely clear to allow ultraviolet (UV) to pass through, a second region is solid to prevent UV light passing through, and a third region includes a plurality of slits acting as a diffraction mask allowing a
20   reduced transmission of UV through the third region of the mask. Because these slits spread the UV light passing through the mask by diffraction, a relatively uniform light intensity may be obtained beneath the slits.

There are three main problems associated with the use of diffraction masks. Firstly, mask cost is a function of the minimum feature size. Smaller
25   feature sizes need more time to write the mask and are therefore more expensive. Diffraction masks need much smaller feature sizes than normal masks, for example gaps and lines of the order of $0.4\mu m$ to $1.5\mu m$ instead of $5\mu m$ for normal photolithography of AMLCDs. This makes the masks expensive and difficult to manufacture. Only a very small number of mask
30   manufacturers have the capability of making such small feature sizes on the large masks used for manufacturing AMLCDs.

Secondly, the uniformity of mask writing is poor for small feature sizes. Since the amount of light reaching the substrate in the diffraction grating area is a strong function of the slit size, a process using such diffraction masks is prone to poor uniformity of photoresist thickness in the areas exposed by the diffraction grid.

Thirdly, the diffraction effect inevitably means that the light intensity profile has sloped edges. The sloped edge of the light intensity profile translates into a sloped edge profile of photoresist. To define the second photoresist pattern the photoresist must be partially etched in an oxygen plasma. The oxygen plasma etch, photoresist spinning and UV exposure are not perfectly uniform for large substrates and this will cause different thicknesses of photoresist to be etched at different positions on the substrate, and this in turn leads to inaccuracies in feature size.

Figure 1 illustrates the effect of this. If the photoresist is partially etched by thickness d_1 the size of the gap is L_1, but if the etched thickness is d_2 then the gap length will be L_2. Thus, small variations in thickness can cause significant variations in feature size. This variation is a problem in applications for which feature size control is important, for example when defining the thin film transistor (TFT) channel length of AMLCDs.

Thus, there remains a need for a process for manufacturing AMLCDs and other devices that addresses these inconveniences.

According to the invention, there is provided a mask, comprising: a mask substrate; a half-tone layer of half-tone mask material arranged in a pattern across the mask substrate; and a light-blocking layer of light blocking material arranged in a pattern across the half-tone layer; wherein the half-tone mask material is silicon-rich silicon nitride $SiN_x:H$ with x in the range 0 to 1.

The mask according to the invention uses silicon-rich silicon nitride. The inventors have realised that this material has a property that makes it very useful in the specific application. Specifically, the fraction x of nitrogen in the mask layer can be varied easily by manufacturing the mask layer using plasma deposition and varying the amounts of ammonia (NH_3) and silane (SiH_4), and

so it is possible to vary the optical band gap of the silicon nitride. Tests carried out by the inventors have shown that the optical band gap of mask silicon nitride is a much more important parameter for determining the optical transmission of a layer of silicon nitride than small variations in the thickness of that layer. Thus, it is possible to accurately control the transmission of ultraviolet light through the half-tone layer of silicon-rich silicon nitride by accurately controlling the fraction of nitrogen in the layer.

Further, it is possible to make masks suitable for a variety of different ultraviolet wavelengths. By varying the fraction of nitrogen it is possible to produce half-tone mask material layers suitable for use with UV light sources having a variety of ultraviolet wavelengths, including the i-line at 365nm, the h-line at 405nm and the g-line at 436nm.

Preferably, the silicon-rich silicon nitride layer has a value of x in the range 0.2 to 0.6 and an optical band gap of from 2.1eV to 2.5eV, preferably less than 2.35eV. The silicon-rich silicon nitride layer preferably has a thickness of from 40nm to 100nm.

The invention also relates to the use of the mask described above to pattern a layer of photoresist by passing ultraviolet light through the mask onto the layer of photoresist to define fully removed regions in which the photoresist is fully removed, thick regions having a first thickness and thin regions having a thickness less than the first thickness in the regions exposed through the half-tone regions.

The invention also relates to a method of manufacture of a mask for use with an ultra-violet light source of predetermined wavelength, comprising: providing a mask substrate; depositing a layer of silicon rich silicon nitride SiN_x:H with a nitrogen fraction x in the range 0 to 1 controlled to provide a predetermined band gap for partially absorbing ultra-violet light of the predetermined wavelength, and depositing an ultra-violet blocking layer on the mask substrate.

In another aspect, the invention relates to a method of manufacture of a thin film device including: depositing multiple layers on a substrate; providing a mask having a mask substrate; a half-tone layer of half-tone mask material

arranged in a pattern across the mask substrate; and a light blocking layer arranged in a pattern across the half-tone layer; wherein the half-tone layer is of silicon-rich silicon nitride $SiN_x:H$ with x in the range 0 to 1; depositing photoresist on the multiple layers on the substrate; passing ultra-violet light
5   through the mask onto the layer of photoresist to pattern the photoresist to define fully removed regions in which the photoresist is fully removed, thick regions having a first thickness and thin regions having a thickness less than the first thickness in the regions exposed through the half-tone regions; carrying out a first processing step on the fully removed regions; thinning the
10   photoresist to remove photoresist in the thin regions but not in the thick regions; and carrying out a second processing step on the thin regions.

For a better understanding of the invention, embodiments will now be described, purely by way of example, with reference to the accompanying
15   drawings in which:
Figure 1 illustrates the variation in feature length due to different plasma etched depths;
Figures 2(a) to 2(e) illustrate stages in the manufacture of a display in a method according to the invention;
20   Figure 3 shows a top view of a TFT manufactured in accordance with the invention;
Figure 4 shows the optical band gap as a function of nitrogen to silane ratio;
Figure 5 shows the transmission as a function of wavelengths and
25   optical band gap; and
Figure 6 shows the optical transmission through different thicknesses of silicon nitride.

Referring to Figure 2, a method of making TFT arrays will now be
30   described. Referring to Figure 2a, a substrate 2 has a layer of silicon nitride 4, a layer of amorphous silicon 6 and a metal layer 8 deposited upon it. A layer of photoresist 10 is then deposited across the substrate. The methods of

depositing such layers are standard and well known in the art. The substrate may be of any convenient material, such as glass.

A photo mask 12 is then provided having a UV-transparent mask substrate 14, a patterned layer of silicon-rich silicon nitride half-tone mask material 16 on the substrate and a chromium light blocking layer 18 over part of the silicon nitride half-tone mask material. The photo mask 12 is thus divided into three regions. In light-blocking regions 20 where the chromium light blocking layer 18 is present UV light is substantially all absorbed by the mask. In clear regions 22 where neither the half-tone mask material nor the light blocking chromium layer is present, UV light passes through the mask with little absorption. In half-tone regions 24, only the half-tone mask material and not the chromium light blocking layer are present. In these regions, the transmission of UV light is in the range 20% to 80%.

The layer of silicon-rich silicon nitride 16 has a thickness of 60nm and a band gap of 2.3eV. These parameters may be varied depending on the UV light properties, as will be explained in more detail below.

The photo mask 12 is placed in registration with the substrate and a UV light source 30 having a predetermined wavelength is directed through the photo mask 12 onto the photoresist 10 to pattern the photoresist. After exposure, the photo mask 12 is removed and the photoresist 10 developed to give two different thicknesses of photoresist.

In regions 32 of the photoresist layer 10 that are exposed through the clear regions 22 of the mask, the photoresist 10 is fully removed forming fully removed regions. In regions 30 corresponding and adjacent to the light-blocking regions 20 of the mask, the photoresist remains with a first thickness forming thick regions. In regions 34 of the photoresist layer 10 that are exposed through the half-tone regions 24, the photoresist 10 is processed to have a reduced thickness less than the first thickness forming thin regions 34. In particular, the reduced thickness is preferably 40% to 60% of the first thickness, further preferably approximately 50%. The steps of exposure of the photoresist 10 and development accordingly result in the pattern shown in Figure 2(b).

The reason that it is possible to process photoresist to have multiple thicknesses is that photoresist contains a photo-active additive that is strongly absorbing for UV light and is a dissolution inhibitor for the bulk of the photoresist polymer layer. Unexposed regions of photoresist can be immersed in photoresist developer for long periods without removing any of the photoresist. On exposure to UV light, photons are absorbed on the top surface of the photoresist. Photo chemical reactions then occur that alter the photo-active additive so that it no longer acts as a dissolution inhibitor. It is also bleached so that UV light can pass through exposed layers deeper into the photoresist layer. The combined action of photo bleaching and destroying the dissolution inhibitor means that UV exposure is a top-down process. If the photoresist is only exposed for a short time so that the complete layer has not be effectively exposed, only the upper parts of the photoresist will be removed in the subsequent development step, leaving a thinner but complete layer of photoresist. Only the layers of photoresist in which there is effectively no longer any dissolution inhibitor will dissolve quickly in the photoresist developer solution.

Thus, by exposing the photoresist 10 through the mask 12 for the correct amount of time and then developing the fully removed regions 32 of photoresist under clear regions 20 of the mask are fully removed and the thin regions 34 of photoresist under half-tone regions 24 of the mask receive only half of the light necessary to expose the whole film and hence about half the photoresist thickness will remain in this region after development.

As shown in Figure 2(c), the next step is to etch both the metal 8 and amorphous silicon 6 layers through the fully removed regions 32.

Next, as illustrated in Figure 2(d), the photoresist 10 is partially etched in an oxygen plasma. This removes the thin regions 34 of photoresist, while still leaving a thin layer of photoresist in the thick regions 30. The new photoresist pattern is then used to etch the metal layer 8 but not the amorphous silicon layer 6, and the photoresist is then removed leading to the pattern illustrated in Figure 2(e).

Figure 3 shows a plan view of an etched source-drain metal layer 8 and amorphous silicon layer 6 in a thin film transistor. It will be noted that the amorphous silicon layer 6 extends under the whole of the regions of the metal source and drain metalisation 8. In other words, the top pattern of the metal layer 8 lies wholly within the boundary of the amorphous silicon layer 6.

The most difficult aspect of this process is to reliably achieve multiple levels of photoresist with a controlled thickness. By using the silicon-rich silicon nitride as the half-tone mask layer, in accordance with the present invention, difficulties associated with diffraction pattern half-tone masks can be avoided. The feature size of the mask matches the size of the features to be patterned, and is not reduced as would be required for diffraction grating approaches. This in turn means that lack of uniformity in mask writing caused by small feature sizes is reduced by the larger feature sizes available using the present approach. Further, the approach avoids the sloping photoresist edges that are characteristic of features patterned with diffraction grating masks, and hence avoids the poor uniformity of feature size associated with such sloping photoresist edges.

The use of silicon rich silicon offers the further benefit that the precise properties of the silicon-rich silicon nitride layer 16 may be varied depending in particular on the wavelength of light emitted by the ultraviolet light source 30.

The silicon-rich silicon nitride may be deposited on the mask using plasma deposition, which makes it possible to deposit silicon nitride SiN_x with a fraction of nitrogen x in the layer varying from 0.001 to 1.4. As the amount of nitrogen increases the optical band gap of the material increases from 1.7eV to 6.0eV. In the invention, the absorption edge of the silicon nitride is controlled to control the amount of light transmitted through the silicon nitride. Typically, UV processing uses the g, h and i emission lines of mercury lights. Therefore, in this case the silicon nitride should have an absorption edge in the region of 400 to 500nm which corresponds to roughly 2.1 to 2.5eV.

Figure 4 shows the band gap of the deposited silicon rich silicon nitride as a function of the ammonia: silane ratio in the plasma deposition process. It

will be seen by varying this ratio, a variety of different band gaps may be obtained.

Figure 5 shows the effect of changing the optical band gap for a 60nm thick layer of silicon nitride. As may be seen, the optical transmission is a strong function of the band gap. Accordingly, by controlling the band gap it is a relatively straight forward problem to accurately control the transmission through the silicon nitride mask layer. Thus, by using silicon nitride obtaining an accurate optical transmission is relatively straightforward. Accordingly, the silicon rich silicon nitride layer 16 may preferably be manufactured to have a band gap in the range 2.15eV to 2.35eV to correspond to the wavelengths of widely used UV light sources 30, in particular the i-line, h-line or g-line of mercury lamps.

The approach of using silicon-rich silicon nitride has the further benefit that the thickness of the silicon nitride layer is not particularly critical. Figure 6 illustrates the optical transmission through different thicknesses of silicon nitride with an optical band gap of 2.3eV. As is clear from the figures, small variations in the thickness of the silicon nitride layer do not lead to wild variations in the transmission. Accordingly, it is possible to reliably obtain a mask layer of substantially uniform transmission across the whole area of the mask. The mask layer thickness may be, for example, in the range 40nm to 100nm.

It will be appreciated that the masks used in the manufacture of active matrix liquid crystal displays are large and so are inherently subject to variation in thickness of mask material across their width. Preferably, the variation in thickness of mask material is no more than 20%, further preferably 10%.

From reading the present disclosure, other variations and modifications will be apparent to persons skilled in the art. Such variations and modifications may involve equivalent and other features which are already known in the design, manufacture and use of masks and which may be used in addition to or instead of features described herein. Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of disclosure also includes any novel feature or

any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to any such features and/or combinations of such features during the prosecution of the present application or of any further applications derived therefrom.

For example, although the example describes the use of a positive photoresist process, a similar approach may be used with negative photoresist.

Further, although the process has been described for use with an AMLCD structure, it is also of use in the manufacture of other structures, for example MEMS, particularly using a combination of metal, silicon, plastic and dielectric layers in a process involving photolithographic patterning. MEMS can have similar feature sizes to thin film devices.